A Minimal State Augmentation Algorithm for Vision-Based Navigation Without Using Mapped Landmarks

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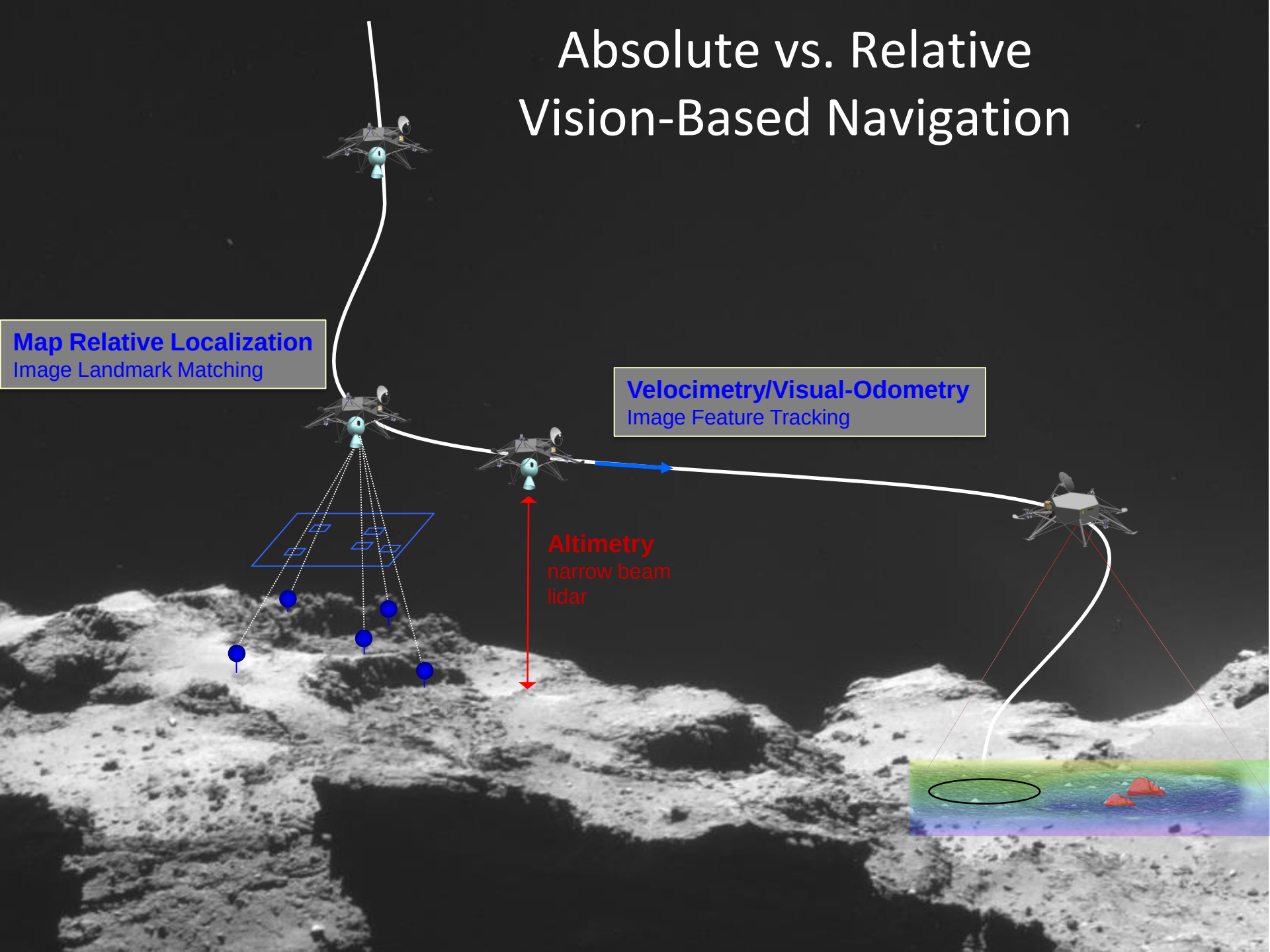
Absolute vs. Relative Vision-Based Navigation



Relative Vision-Based Navigation

Existing algorithms assuming standard sensor suite (IMU, camera, altimeter):

- Simultaneous Localization and Mapping (SLAM)
  - Requires the augmentation of the estimated state vector by 3xN states, where N is the number of tracked features
    - Large number of on-board computations
    - Numerical instability issues
  - Requires motion to solve for the feature locations and compute vehicle delta-pose

- Optical Flow, Epipolar Plane
  - Requires motion to solve for delta-pose

Proposed Vision-Based Navigation

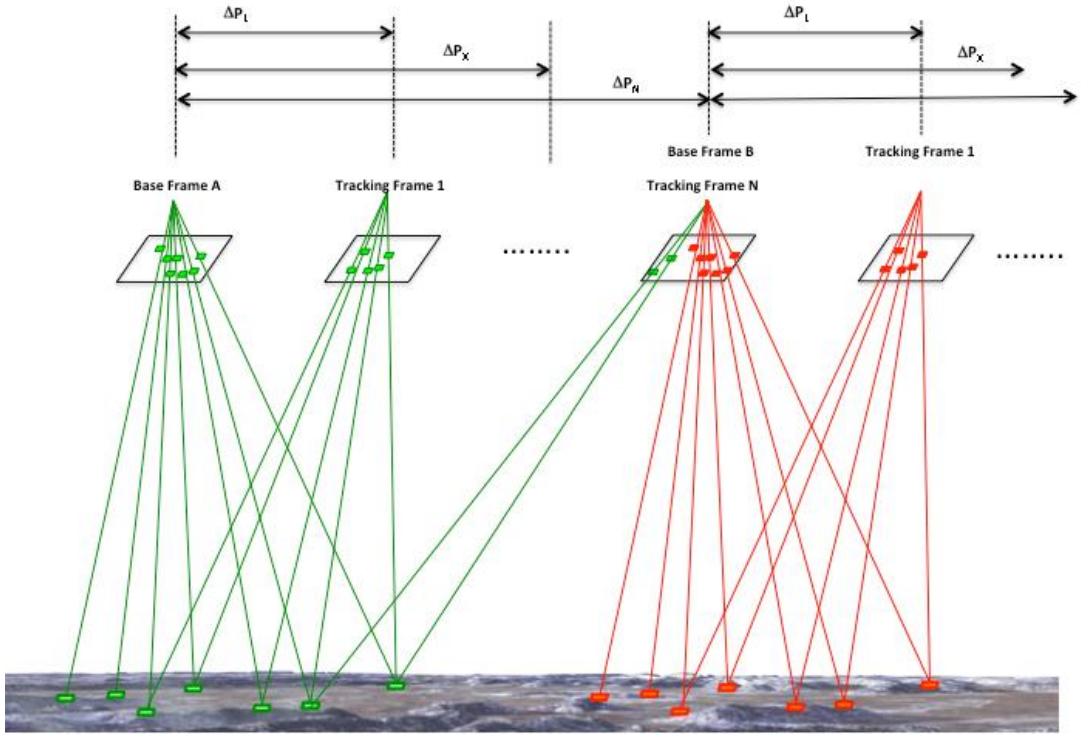
- This paper will describe MAVeN (Minimal State Augmentation Algorithm for Vision-Based Navigation), an algorithm for Absolute and Relative Vision-Based Navigation
  - The motivation, assumptions, architecture, derivation, and its performance

Major Assumptions of MAVeN

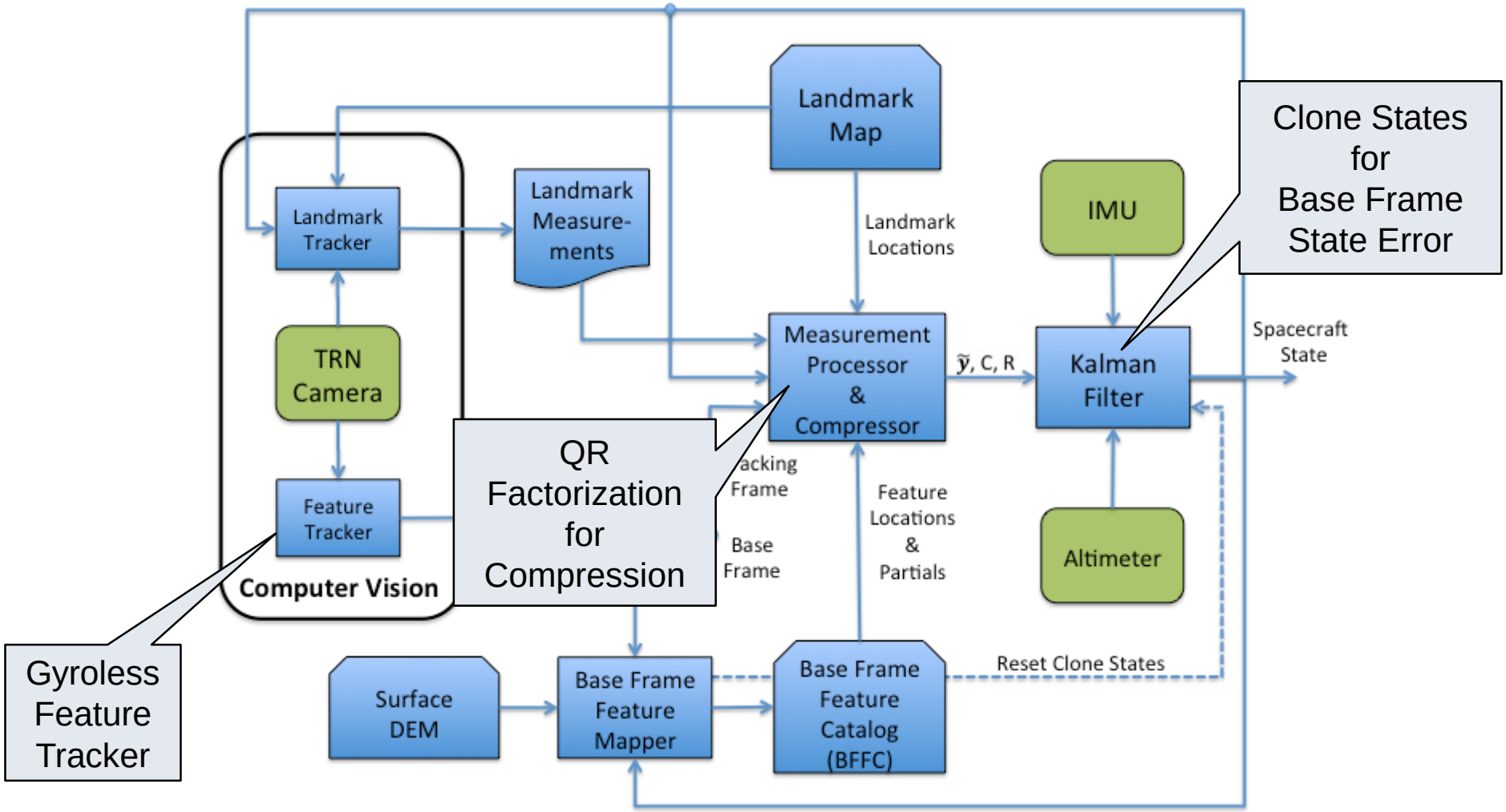
- We know the surface we are going to perform proximity operations and land on
  - We have an on-board Shape Model (DEM, Facets, …) of the surface
- We have a good initial estimate of the spacecraft state in the body frame
  - Attitude provided by Star Tracker and rotational model of the natural body
  - Position provided by Ground Navigation or Absolute Visual-Based Navigation
- Note: The need for the Shape Model and the position knowledge assumption can be relaxed if the surface can be approximated by a planar surface

Major Design Feature of MAVeN

- Base Frame feature locations are projected onto the Shape Model of the body surface to generate Pseudo-Landmarks which are tracked in following Tracking Frames in order to generate a delta-pose measurement
- The error in the location of the Pseudo-Landmarks are represented in the partials of the measurement matrix using the local surface slopes, also included in the Shape Model



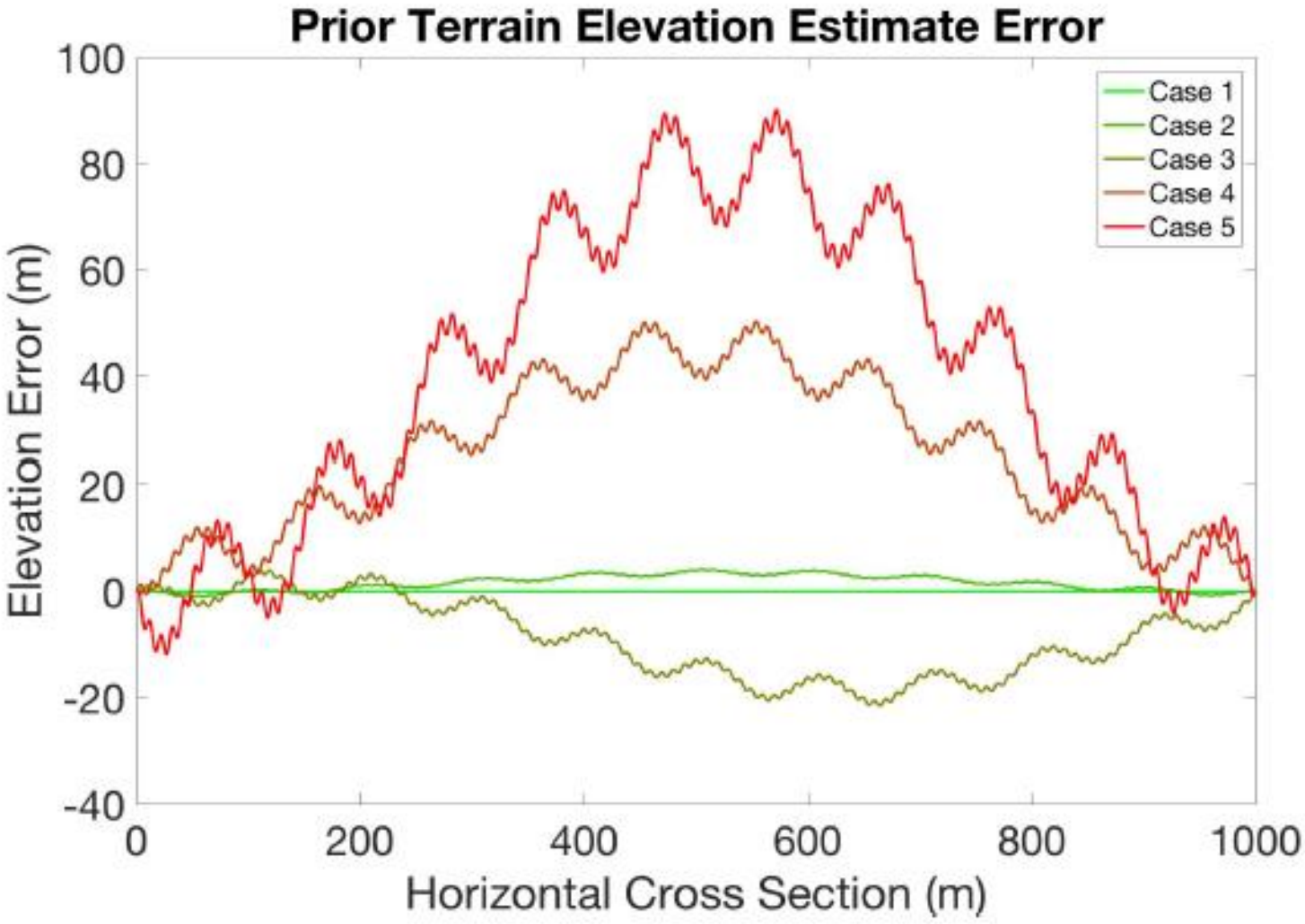
Filter Architecture



Filter Performance

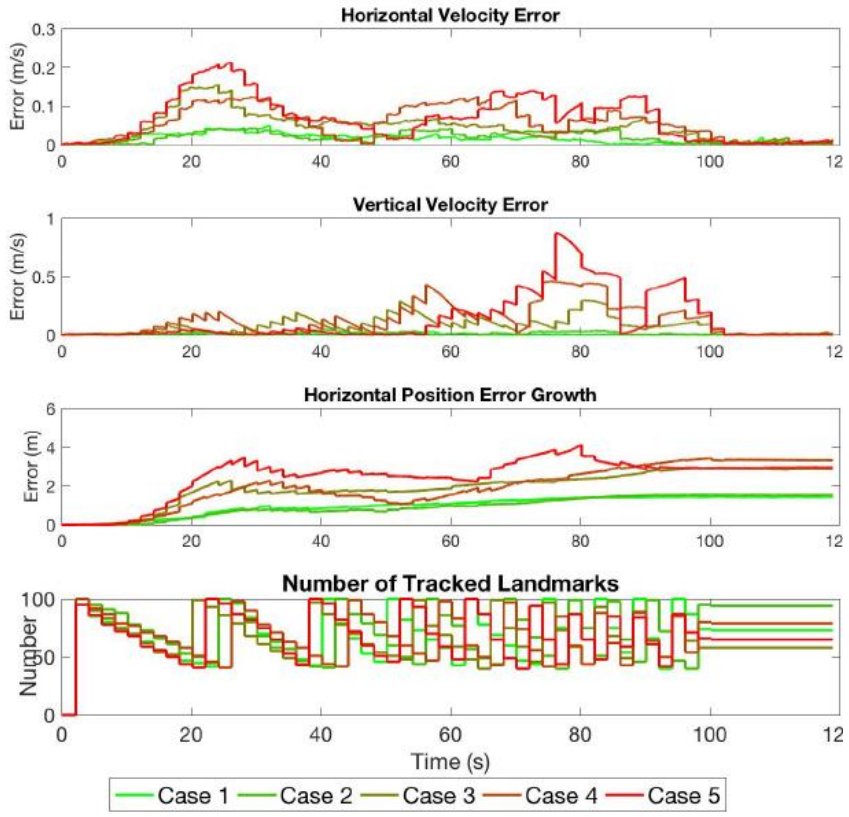
- Test Scenario
  - Vertical descent from 1000 to 10m
  - Constant deceleration from 20 m/sec to 0 m/sec
  - Constant attitude
- Sensors
  - MIMU class IMU
  - Camera: 60deg FOV, 1000x1000 pixels with a 0.5Hz update
  - Feature centroiding error of 2 pixels
  - LIDAR Altimeter: 0.5m error at 5Hz
- MAVeN
  - Translation Only (MAVeN-T)
  - Attitude and Translation (MAVeN-AT)
  - Planar Surface Assumption

Truth Terrain Model

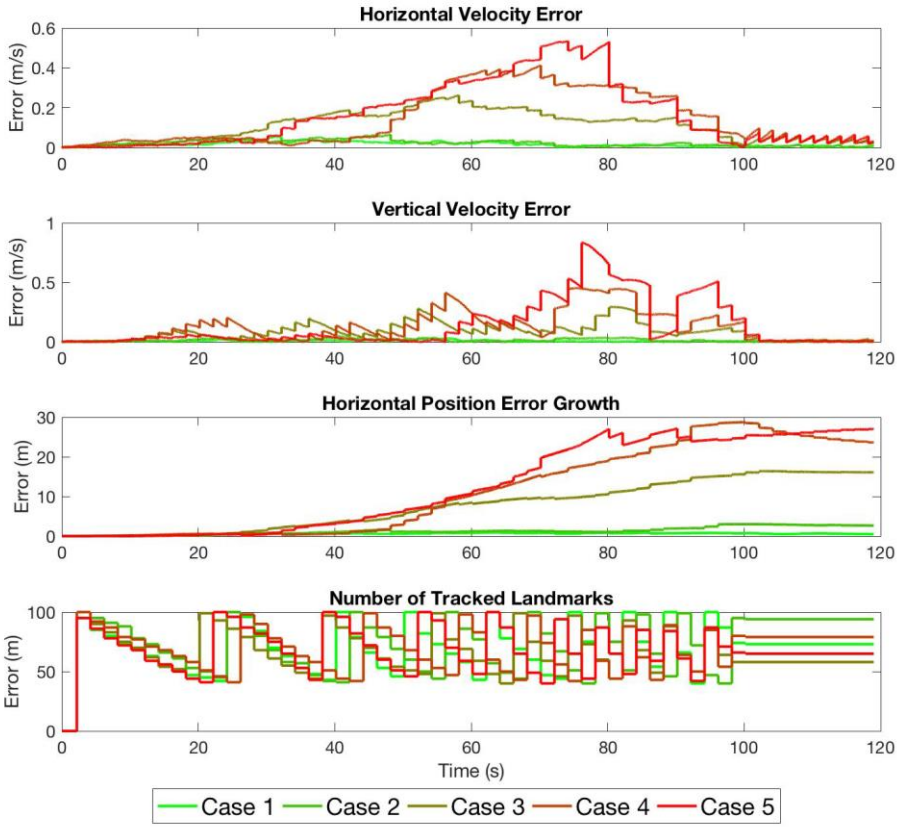


Results

MAVeN-T



MAVeN-AT

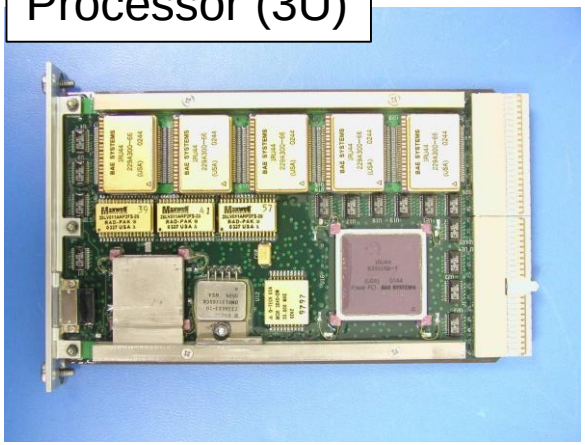


Results (Cont.)

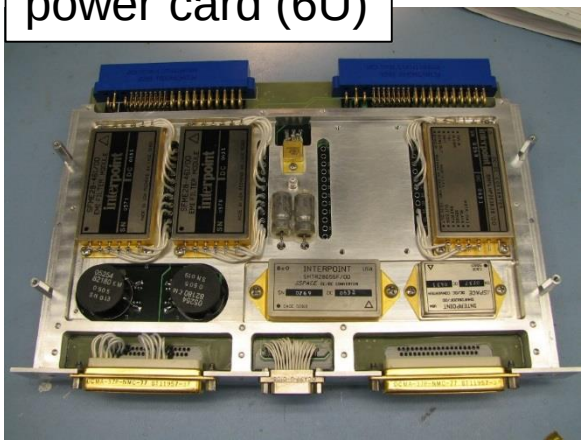
Case	Horizontal Velocity Error		Vertical Velocity Error		Horizontal Position Error	
	MAVEN-AT	MAVEN-T	MAVEN-AT	MAVEN-T	MAVEN-AT	MAVEN-T
Case 1	0.71 cm/s	0.73 cm/s	0.30 cm/s	0.30 cm/s	0.57 m	3.39 m
Case 2	0.58 cm/s	0.46 cm/s	0.34 cm/s	0.34 cm/s	2.35 m	2.58 m
Case 3	1.73 cm/s	0.49 cm/s	0.44 cm/s	0.40 cm/s	10.41 m	2.48 m
Case 4	2.49 cm/s	0.60 cm/s	0.47 cm/s	0.48 cm/s	19.07 m	3.20 m
Case 5	4.62 cm/s	0.48 cm/s	0.44 cm/s	0.38 cm/s	32.85 m	8.70 m

Vision Compute Element for Mars 2020 TRN

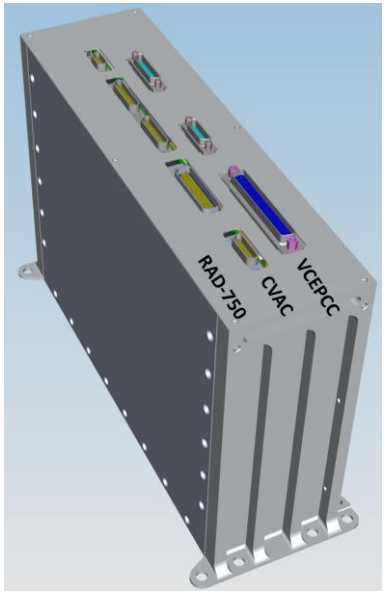
Flight RAD750 Processor (3U)



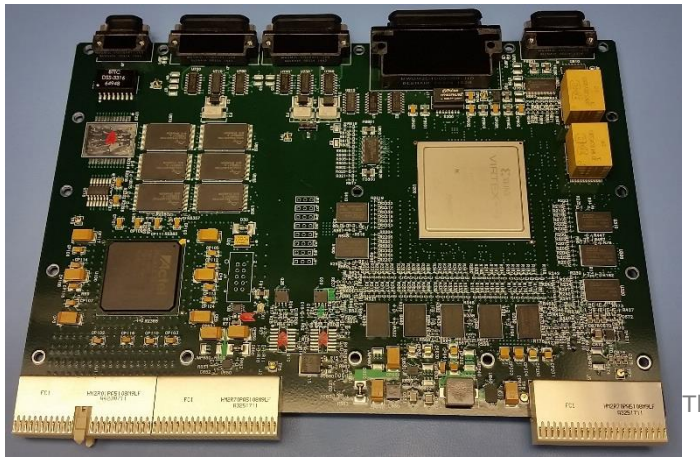
Flight-qualified power card (6U)



6U cPCI chassis and backplane



Computer Vision Accelerator Card (CVAC) (6U)



The Vision Compute Element (VCE) is a 3 slot 6U processor with a RAD750 general purpose processor, a power conditioning card (CEPCU1) and a Virtex5 enabled Computer Vision Accelerator Card (CVAC).

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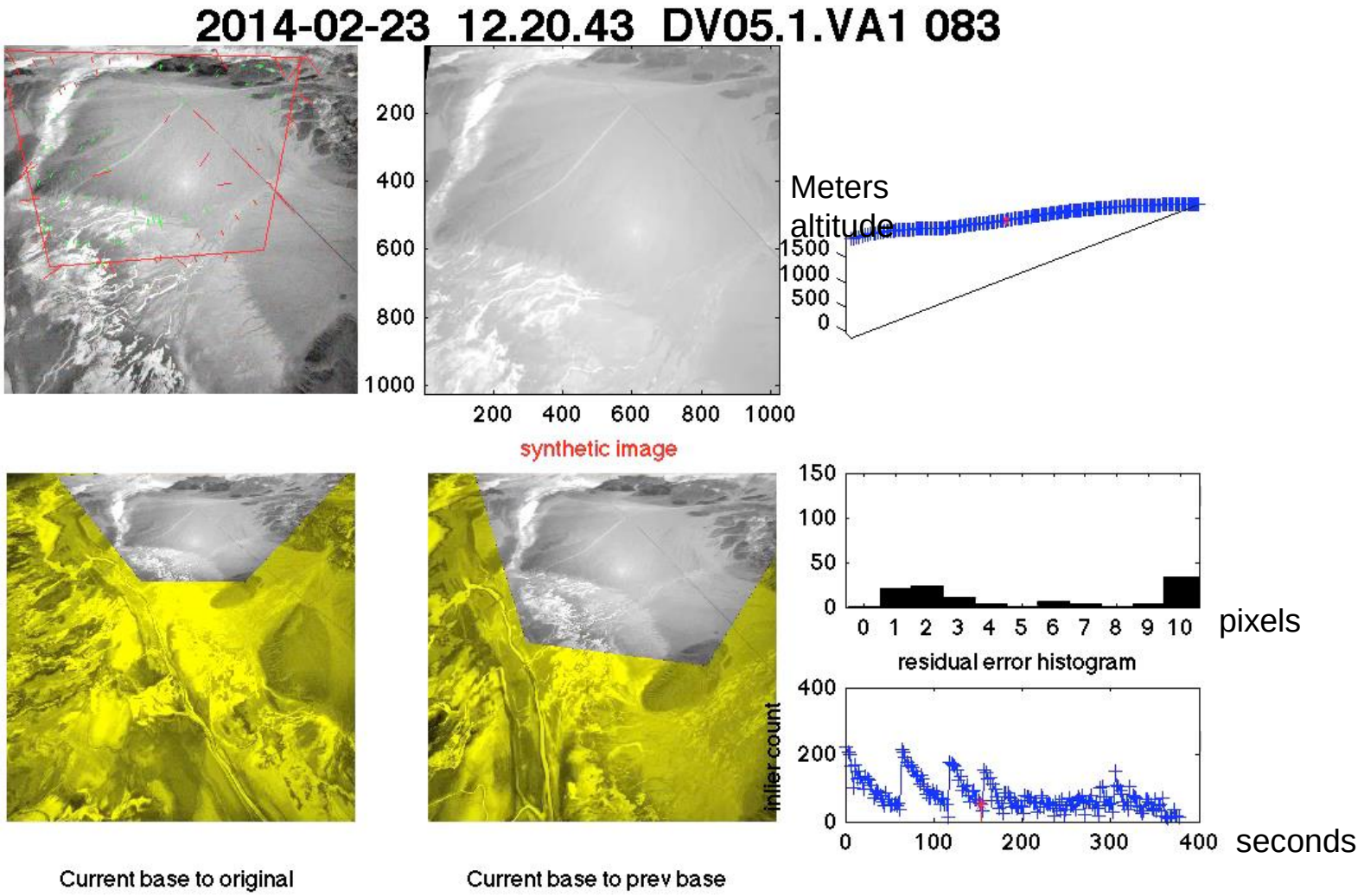
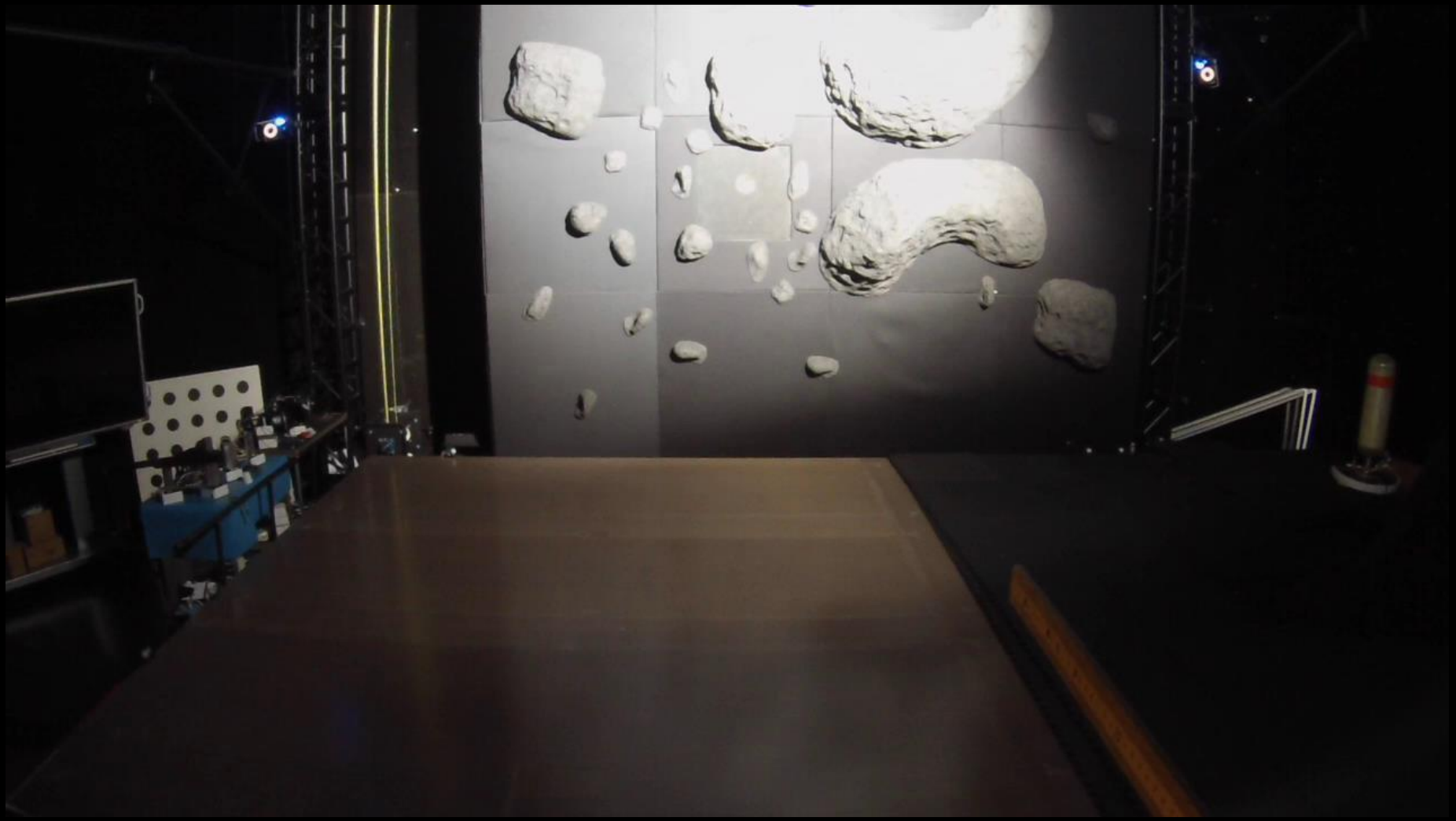
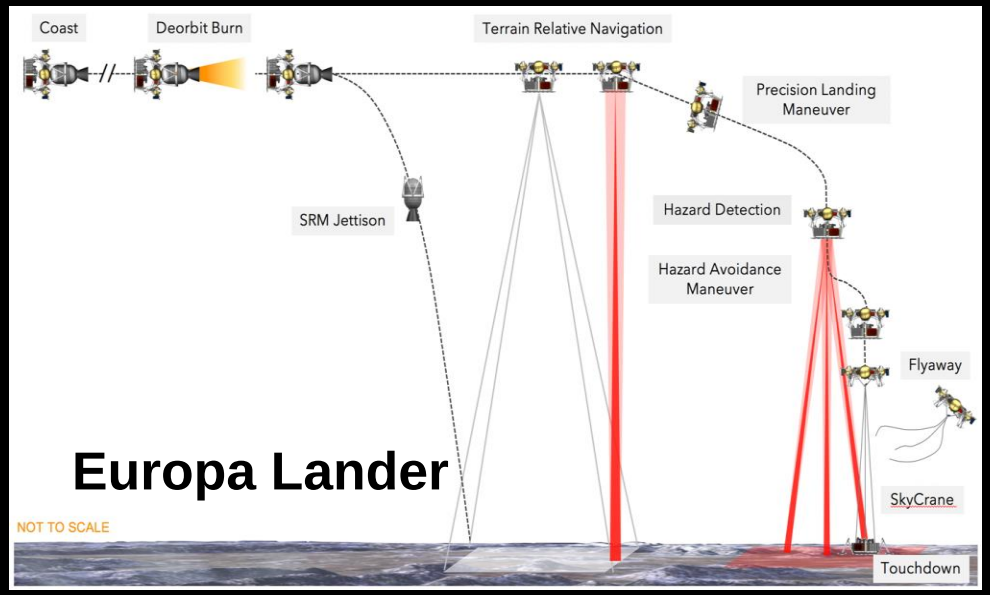
Gyroless Feature Tracker Field Test



MAVeN Real Time Test - Tracking Wall



MAVeN Potential Applications



Pre-Decisional Information -- For Planning and Discussion Purposes Only

Conclusions

- A new algorithm was developed combining Absolute and Relative Vision-Based Navigation, LIDAR altimeter, and IMU
- MAVeN's major architectural feature is the ability to do Feature Tracking with a minimum augmentation of the state vector
  - Requires a shape model and good initial knowledge of vehicle pose relative to the surface

  or
  - A surface that can be approximated by a plane
- Performance of the filter for the planar surface assumption case was evaluated with different surface model errors and the results are very encouraging